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An Overview of Non-Traditional Nuclear Threats

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Pacific Northwest National Laboratory

Nuclear Threat Vectors

- Traditional Triad
  - Sea-Based Missiles
  - Land-Based Missiles
  - Bombers
- Other
  - Special Forces
  - Other
- Non-Traditional
  - Sea Cargo
  - Truck Cargo
  - Rail Cargo
  - Air Cargo
  - Passengers & Luggage
    - Commercial Aviation
    - General Aviation
    - Cruise Ships
    - Private Auto
  - Other
    - Fishing Boats
    - Private Yachts

Traditional Vectors

Missiles &
Bombers &
Special Forces

Non-Traditional Vectors

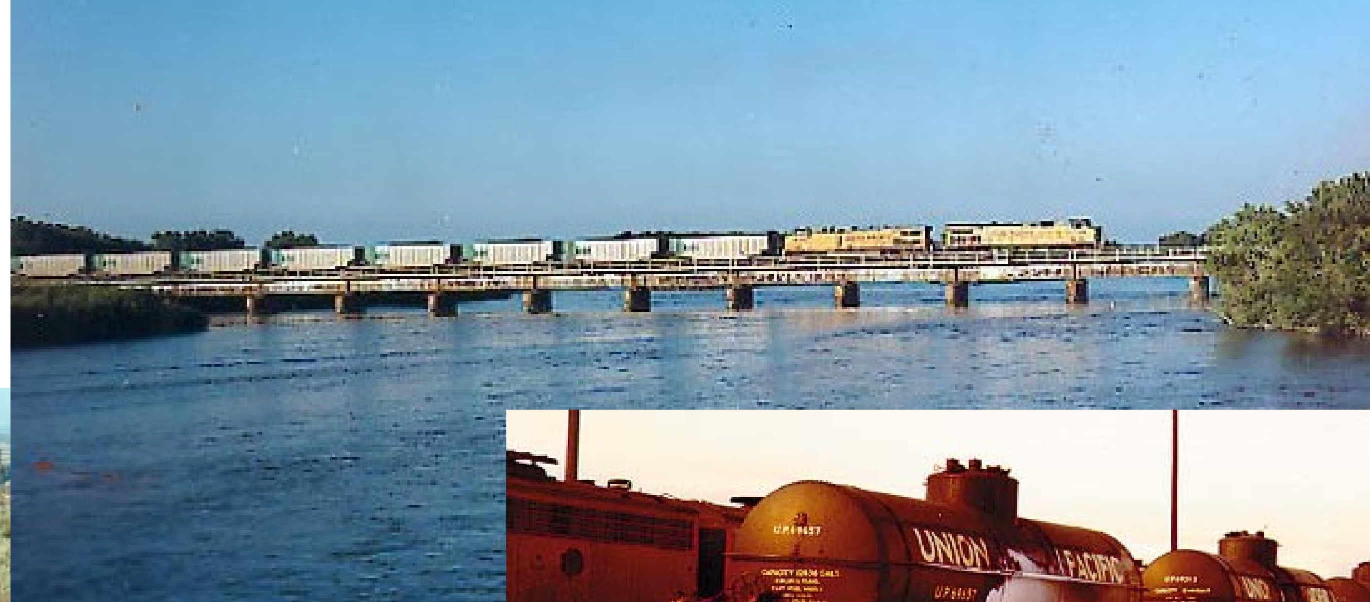
Port of Portland – Terminal 6

Large Operation: Sea, Truck & Rail

Processing a Sea Container

X-raying a container

The Rail Vector




SEABOARD
U.S.
CUSTOMS
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Defense


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Threat Consequences

- Smuggled nuclear warhead denotation
  - Weapon of Mass Destruction
  - Massive direct loss of life and physical damage
  - Loss of a major US city – Permanent?
  - Economy crippled if cargo container shipping eliminated
  - Denotation in port is bad – Near a major city
- RDD denotation or failed-yield warhead
  - Weapon of Mass Disruption
  - Potential for major economic disruption – High cost
  - Psychological damage and terror
  - Temporary loss of immediate area & some lives potentially lost
  - Clean-up/decontamination costs

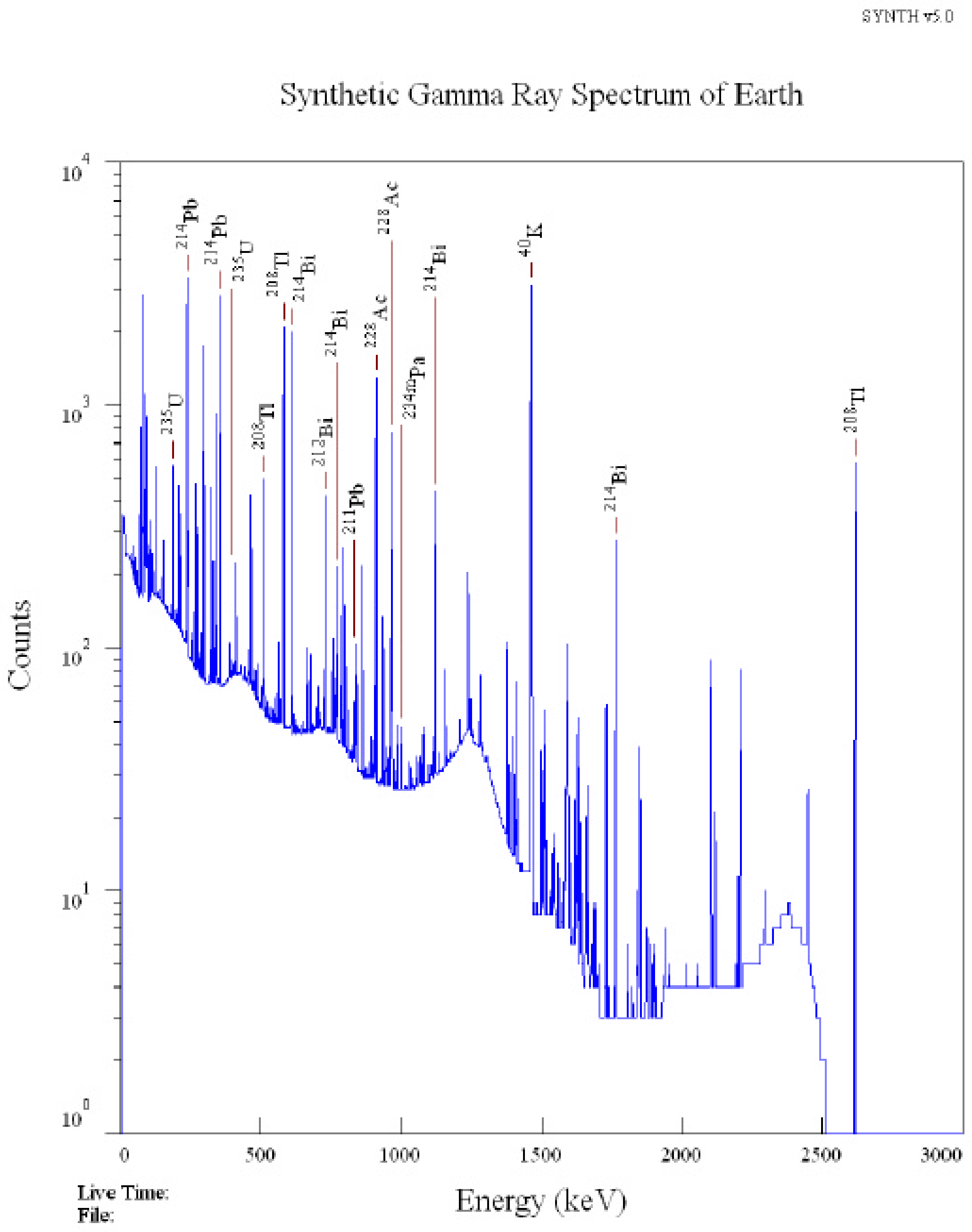
The Technical Challenge

- The amount of radiation emitted – Signal strength
  - Unexploded nuclear weapon is modest source – no health risk
  - Unshielded RDD would be a strong source – potentially lethal
- Shielding reduces the radiation signal by $e^{-\mu x}$
  - Other surrounding cargo in a container reduces the signal
  - Engineered shielding can greatly reduce the signal
- The distance between source and sensor reduces the signal by $1/r^2$
- Natural radiation is concentrated in some products

  (e.g., ^{40}K in bananas and ^{232}Th in welding rods)
- Radiation sources can be found in innocent cargo

  (e.g., ^{241}Am in smoke detectors)
- The natural radiation background is not spatially or temporally stable and must be accommodated

Earth Background

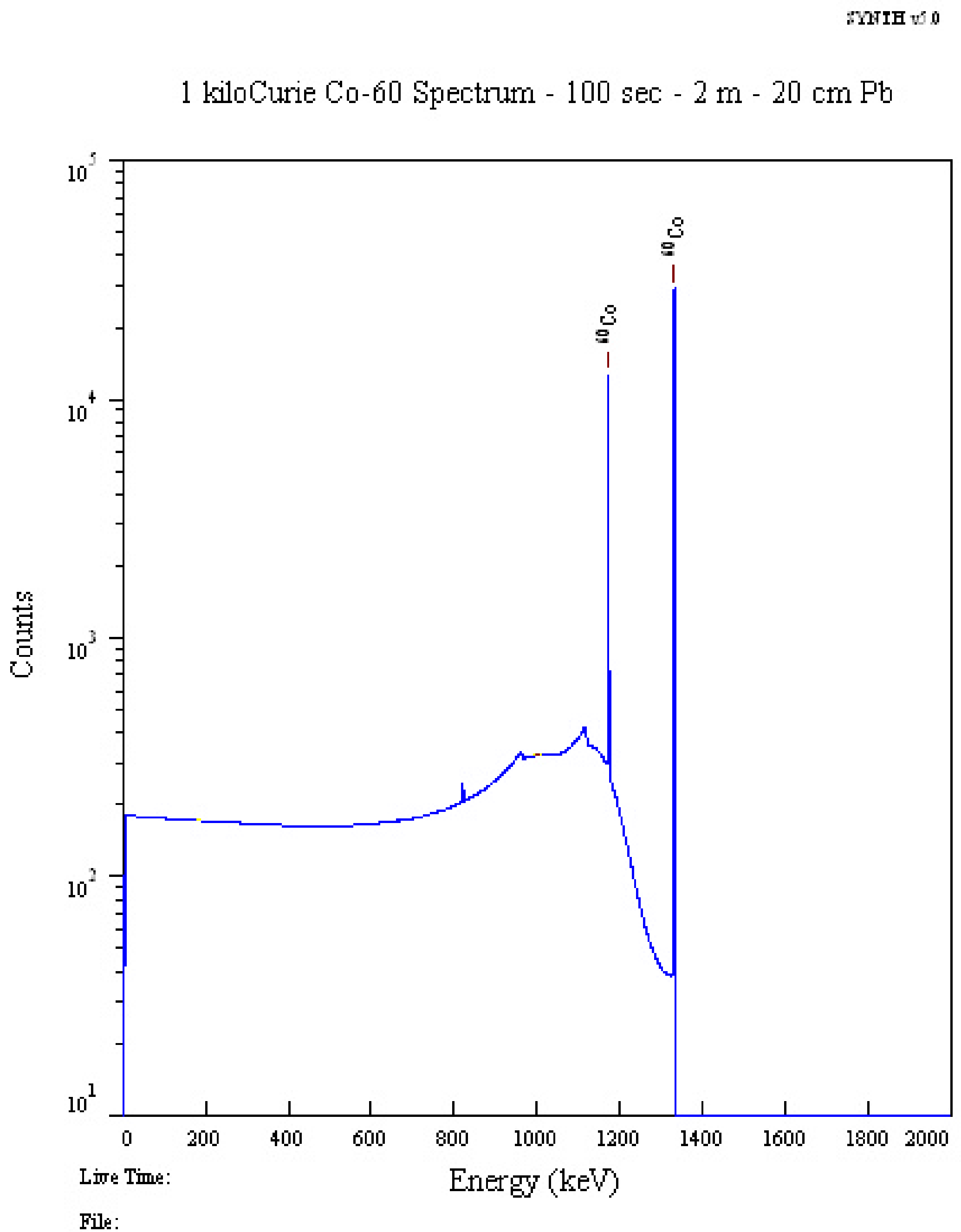


- 100,000 seconds
- 1 meter standoff
- 140% HPGe sensor
- 25 kg soil disk 10 cm thick

- Many peaks
- Complex spectrum
- SYNTH spectrum is only qualitative
- Scattered gammas problematic
- Background is due to great mass of surrounding materials hence x1000 longer time

Radiation Dispersal Devices

- Large amount of radioactivity necessary to effectively contaminate a reasonable area → Readily detectable
  - 1 kiloCurie of ^{60}Co = 3.7×10^{13} decays/sec
    - 1,300 R/hr at 1 meter & lethal dose within 20 minutes
      → Forces use of shielding
    - 5 mrem/hr dose over 1 km^2 when dispersed
      → Forces radiation zone & public exclusion
    - 3.5 grams of ^{60}Co fits in 1 cm^3
- Gamma ray energy depends on the RDD radionuclide
  - ^{60}Co → 1173 & 1332 keV gamma rays
  - ^{137}Cs → 661 keV gamma ray
- Beta-decay-only radionuclides (e.g., ^{90}Sr) can be detected by Bremsstrahlung gamma rays
- Spent Fuel detectable by neutrons and gamma rays



Possible RDD Spectrum

- 100 seconds
- 2 meter standoff
- 140% HPGe sensor

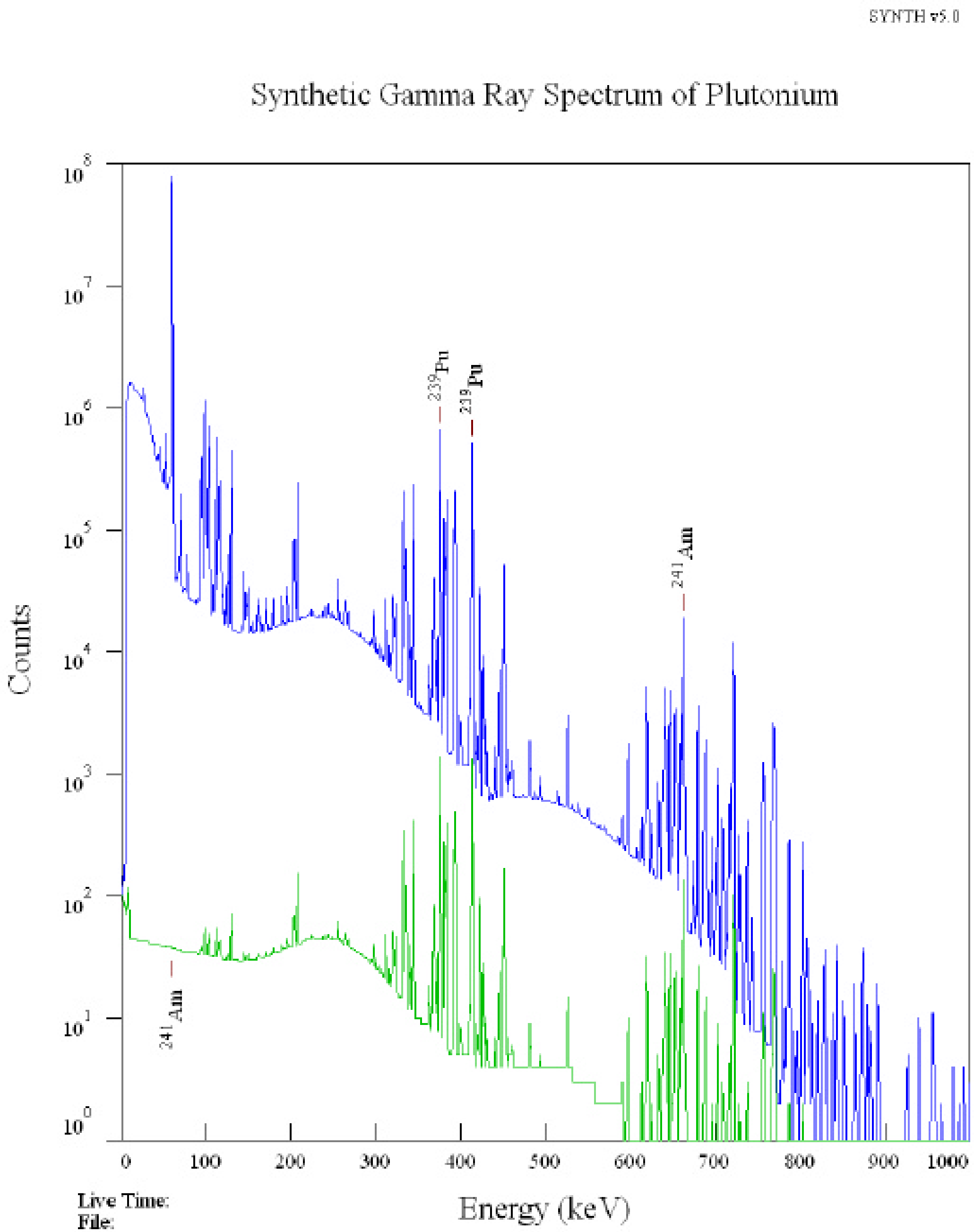
- 1 kiloCurie of ^{60}Co
  - 5 grams of cobalt
  - 5 cm^2 disk
  - 0.11 cm thick

- Substantial shielding
  - 20 cm (8”) thick Pb

Nuclear Warhead Signatures

- Weapons Grade Plutonium (WGPu)
  - 94% ^{239}Pu → 414 keV gamma ray
  - 6% ^{240}Pu → spontaneous fission neutrons
  - ^{241}Am → 60 keV & 662 keV gamma rays
    - Grows in as ^{241}Pu decays with 14.4 yr half life
  - IAEA "significant quantity" = 8 kg
- Highly Enriched Uranium (HEU)
  - 93% ^{235}U → 186 keV gamma ray
  - 7% ^{238}U → 1001 keV gamma ray from ^{234m}Pa
  - IAEA "significant quantity" = 25 kg
- Density of material – X-ray or transmission image
  - U 18.95 gm/cc Pu 19.84 gm/cc
  - Pb 11.35 gm/cc W 19.3 gm/cc
  - Cargo 0.4 gm/cc Sand 1.6 gm/cc Fe 7.87 gm/cc
- Metallic – Metal detection

Plutonium Spectrum



- 100 seconds
- 2 meter standoff
- 140% HPGe sensor
- 20 cm radius disk

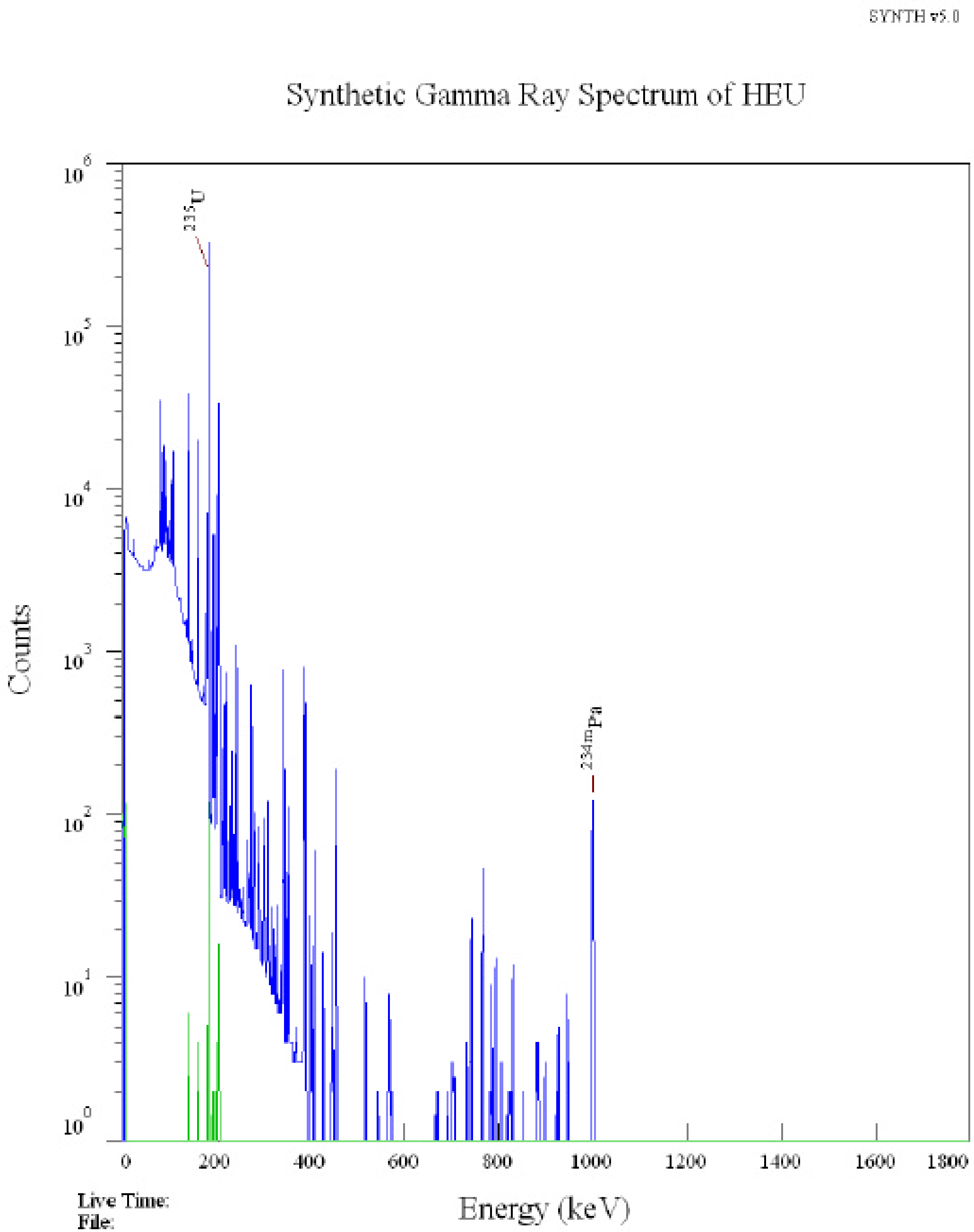
Top plot – Empty container

- Self-attenuation only
- Many peaks

Lower plot – Generic cargo

- Self-attenuation
- 1 cm Fe
- 50 cm polyethylene
- 60-keV peak eliminated
- Down by factor of 100

HEU Spectrum



- 100 seconds
- 2 meter standoff
- 140% HPGe sensor
- 20 cm radius disk

Top plot – Empty container

- Self-attenuation only
- Many peaks

Lower plot – Generic cargo

- Self-attenuation
- 1 cm Fe
- 50 cm polyethylene
- 186-keV peak ~ 1/4000
- Low count spectrum

Difficulties with Passive Radiation Measurements

- Limited radiation signal
- Self-attenuation within fissile material
- Attenuation within other warhead material
- Attenuation within surrounding cargo
- $1/r^2$ spatial dilution with standoff distance
- Signals must exceed background rates for rapid detection
- Variable radiation background rates
- Some cargo contains benign radiation sources
- Operational limitations on measurement time
  ~ 1 - 100 seconds for primary screening
- Expert analysis to fully understand the signals

Gamma Rays versus Neutrons

Gamma Rays

- Present in natural materials
  - ^{40}K, ^{232}Th, ^{238}U & ^{137}Cs fallout
- Full energy is crucial to a unique weapon signature
- 2-10 scatterings prior to photoelectric effect capture
- Dense metals shield
- Background
  - Due primarily to environmental radionuclides
  - Spatial variations in nature
  - Temporal variations - radon

Neutrons

- Unique to Pu nuclear weapons
- Energy not part of unique weapon signature
- 30-50 scatterings prior to thermal capture
- Difficult to shield
  - Thick low-Z materials
  - Channel out through cracks
- Background
  - Due primarily to cosmic rays
  - 1/1000 of gamma ray background
  - Stable background

Gamma Ray Detector Types

- High Resolution – HPGe
  - Small size – Largest is ~140% – 8.6 cm diameter – 60 cm^2
  - Easy ID of SNM peaks
  - Reduced background in narrow peak region
- Modest Resolution – Na(Tl)
  - Modest Sizes – typical logs are 16”x4” – 413 cm^2 – x7
  - Can readily distinguish SNM types
- Plastic Scintillator
  - Large Area – 0.5 to 2 m^2 possible – x80 to x330
    - Great statistics from high count rates
    - Low cost/area
  - Crude Energy Discrimination – Compton only

Neutron Detector Types

- Gas Proportional Counters
  - ^{3}He – Expensive
  - BF_3 – Corrosion and Environmental problems
- ^{6}Li loaded glass
  - Scintillation detectors
  - Optical fibers
    - Large areas possible
    - Expensive
    - Conforms to desired geometries

Other Detection Schemes

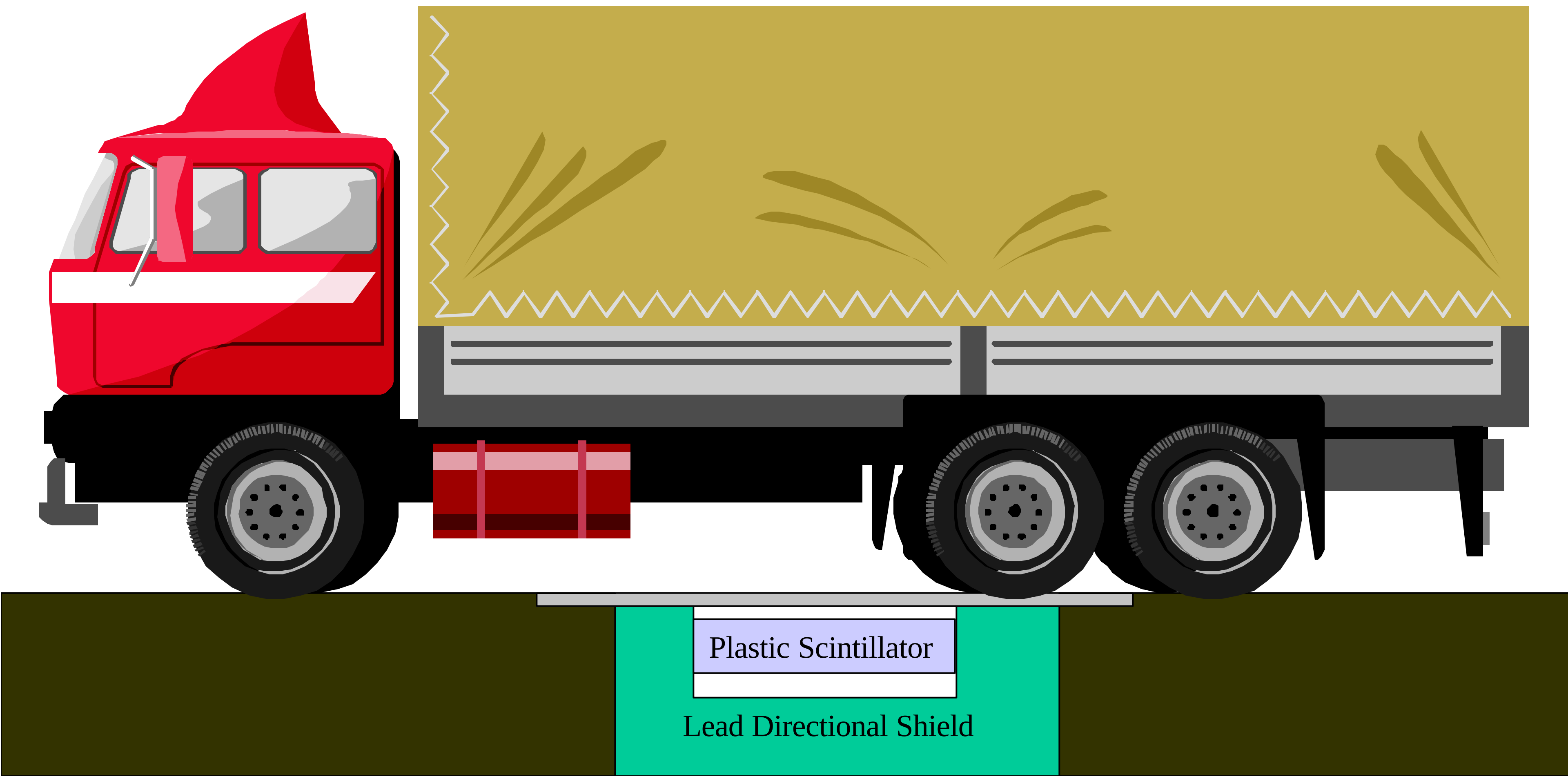
- Passengers & Small items scenario
  - Metal detection – Shielding materials & SNM
  - Weight anomalies – dense/heavy materials
  - X-ray imaging – Airport luggage screening
  - Millimeter wave imaging – Metals or dense items
- Transmission Imaging – Shielding & SNM
  - X-Rays – Limited thickness
  - High-Energy Gamma-Rays or Bremsstrahlung
  - Neutrons
- Thermal – Infrared imaging
- Induced fission – Active radiation probe for SNM

How to Aid Detection

- Minimize $1/r^2$ dilution
  - Place sensors as close to surveyed object as possible
- Minimize attenuation in surrounding cargo – $e^{-\mu x}$
  - Sensors on both sides of container
  - Avoid looking through multiple containers
- Maximize signal-to-noise ratio – $S/\sqrt{B}$
  - Large-area sensors rapidly get good statistics – $\sqrt{A}$
  - Reduce background – $1/\sqrt{B}$
    - Collimate the sensor field-of-view to object
    - Look into region of low background – minimizes shadow shielding of background sources by a surveyed object
- Use spatial information from drive-by survey

Under Roadway Survey

- Large sensor area → High count rate
- Collimated sensor → Block background from soil
- Low background in field-of-view direction → Stable background



A Survey Strategy

- Primary Screening → Rapidly release majority
  - High throughput an operational necessity – $
  - Must spot all threats
    - Must survey all containers – Sampling not an option
    - Need high detection probability
    - Design for most difficult case: Shielded source
  - Accept systematic false alarms due to
    - Concentrations of natural radionuclides
    - Concentrations of dense materials
- Secondary Screening → Evaluate suspect items
  - Survey all containers flagged as suspect
  - Also survey any high-risk or random selections
  - More measurement time per container available
  - Identify any real threats within the smaller population

Survey Strategy Implementation

- Primary Screening → Rapidly release majority
  - Large-area passive radiation sensors – Radiation
  - Crude transmission imaging – Shielding
  - Special case: Passengers & Luggage
    - Metal detection – SNM & shielding
    - X-ray imaging – SNM & shielding
    - Weight anomalies – shielding & warheads
- Secondary Screening → Evaluate suspects
  - Spectroscopy – Identify SMN or RDD radionuclide
  - Higher resolution transmission imaging – Shielding
  - Unload and examine
  - Confiscate / Disarm